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**WELD RADIOGRAPH ENIGMAS**

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## WELD RADIOGRAPH ENIGMAS

by

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### ABSTRACT

Weld radiograph enigmas are features observed on X-ray radiographs of welds. Some of these features resemble indications of weld defects, although their origin is different. Since they are not understood, they are the source of concern. There is a need to identify their causes and especially to measure their effect on weld mechanical properties. A method is proposed whereby the enigmas can be evaluated and rated, in relation to the full spectrum of weld radiograph indications. This method involves a "signature" and a magnitude that can be used as a quantitative parameter. The signature is generated as the difference between the microdensitometer trace across the radiograph and the computed film intensity derived from a thickness scan along the corresponding region of the sample. The magnitude is the measured difference in intensity between the peak and base line values of the signature. The procedure is demonstrated by comparing traces across radiographs of a weld sample before and after the introduction of a hole and by a system based on a MacIntosh mouse used for surface profiling.

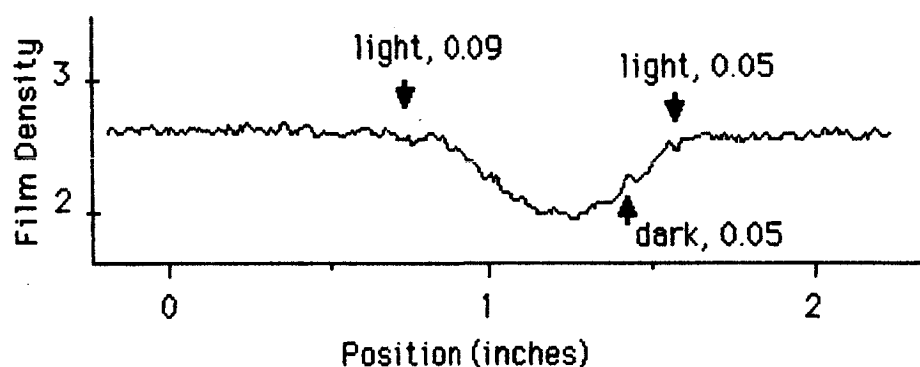
### ACKNOWLEDGEMENTS

The research project took a turn from the anticipated X-ray physics towards a new approach to non-destructive evaluation. The close liaison with colleagues at Marshall as well as at the Martin Company in New Orleans, who were in frequent telephone contact and made a few visits is very much appreciated. Claude Williamon was very helpful in radiography. The success of the research depends directly on the microdensitometer measurements made by Walter Fountain. I am indebted to the encouragement of my counterpart, Dr. Arthur Nunes, who continually supplied information and encouragement. Jeff Ding has been a good colleague on the Enigma project. Carl Wood, is especially appreciated.

## INTRODUCTION

The structural aluminum alloys in the space shuttle external tank are joined by arc welding. One of these processes is relatively new, and produces welds that are free of visual defects. However, to the consternation of every concerned person, weld radiographs occasionally show indications (visual features) that resemble those of some defects. Detailed study has shown, so far, that these indications are not related to defects.

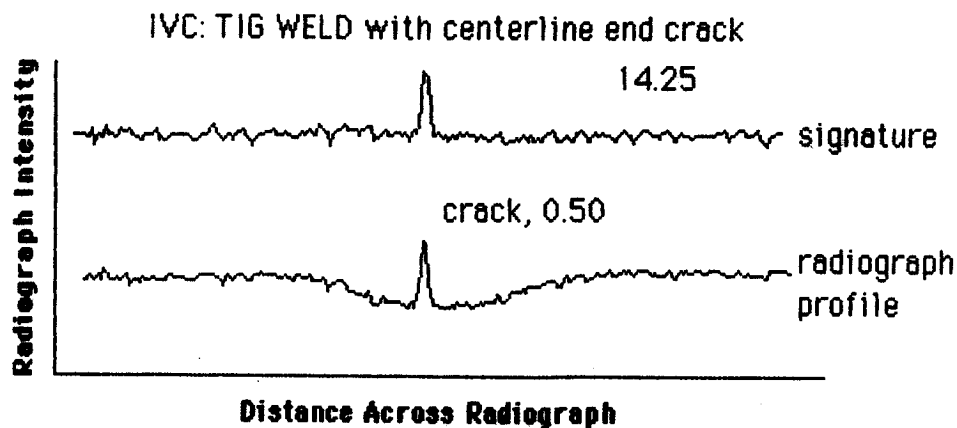
The weld radiograph enigma, (WRE), was found to be any of a number of visually observed details of fine structure in an X-ray radiograph of a weld (1). The following figure, which is based on a previous report illustrates the relative magnitude of "enigma" indications. This figure is a microdensitometer trace across the weld radiograph in the region with the enigma indications. The arrows mark the features of the trace that correspond to the positions of the indications. The designations correspond to the "light line" and "dark line" designations commonly applied and the numbers are the values of the film density at the principal point of the indication relative to the value in the surrounding region.



**Figure 1. Microdensitometer trace across radiograph of weld containing enigma indications.**

There are numerous references to enigmas in connection with welds in a variety of alloy systems and in connection with a variety of welding methods (2). The curves of Figure 2, which are based on the same previous work, provide contrast between the enigma indications and indications of true weld defects. The lower curve is a reproduction of a microdensitometer trace across a radiograph of a TIG weld with a centerline crack. The intensity increment, above the base line, is 0.50 intensity units. A procedure was used to eliminate shape effects, thus effectively straightening the base line, with the result shown in the upper curve. The "signature" of the centerline crack is, therefore, a single, pronounced peak on a featureless base line. The magnitude of this indication is computed as 14.25 pixels on the scale of the

computer screen, or 0.50 intensity units.



**Figure 2. Microdensitometer trace and signature of radiograph of weld with centerline crack.**

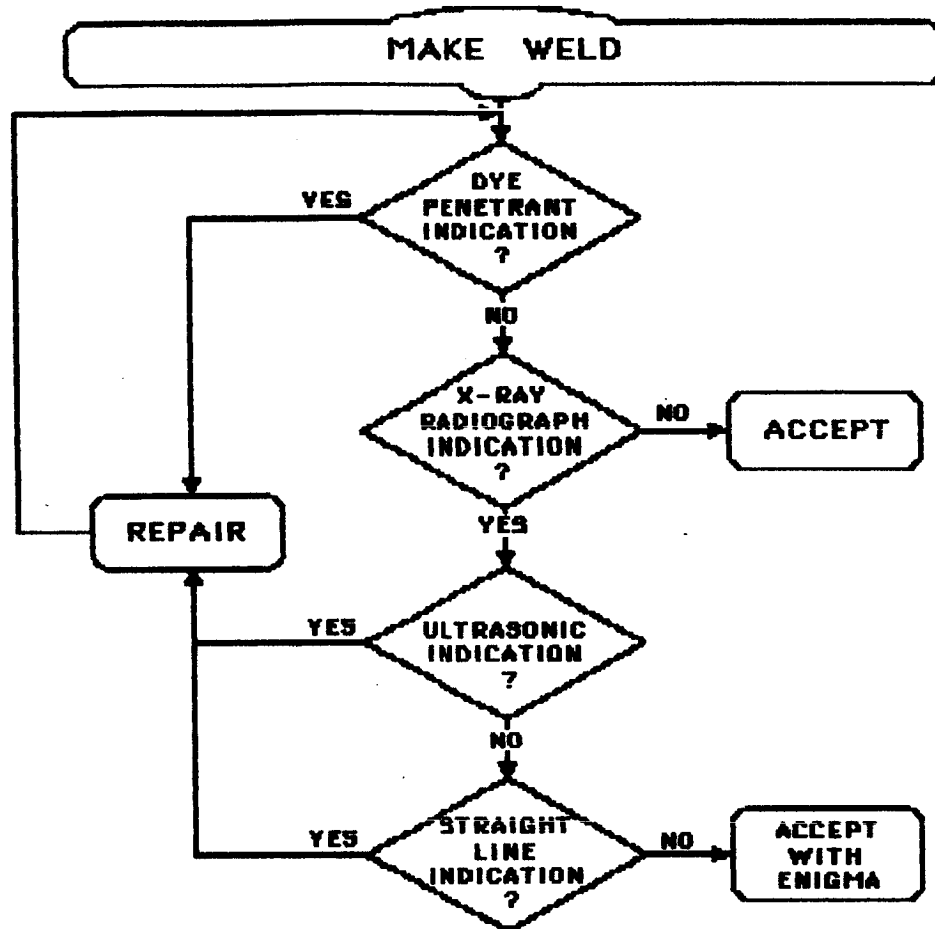
The WRE presents a problem in welding structural members for space vehicles since it forces the acceptance of structures over which there is a degree of uncertainty. The production inspection procedure shown in figure 3 is representative of current practice.

The weld is tested by dye penetrant and radiography. Any indication from the dye penetrant test requires repair welding, without further question. The repaired portion must be put through the entire test procedure. If there are no dye penetrant indications, meaning that there are no cracks that contact the surface, the radiograph is examined for any indications. If there are none, the weld is accepted for use.

If there are radiographic indications, the indicated portions are inspected by ultrasonic reflection techniques. A positive indication from this test procedure is regarded as evidence of lack-of-fusion, or other serious structural discontinuity and the defective section is repaired and reinspected.

If there is no ultrasonic indication, the appearance of the radiographic indication is considered. If any is found in the category of a straight line feature, it is repaired. If not, the weld is accepted. With either alternative, there is doubt about the decision. On the one hand, there is the possibility that an unnecessary repair was made. On the other, there is the possibility that a weld of unknown quality was accepted. The problem is that some indications are so positive that the question remains whether the weld is structurally acceptable. The solution to the problem requires that the cause be understood and second that the effect on properties, specifically on design allowables, be understood.

Specifically, a knowledgeable basis for the acceptance or rejection of welds in flight hardware and other service structures is needed.



**Figure 3. Weld inspection procedure.**

The direct approach to a solution of the enigma is to understand the occurrence of each type and to measure the effect on weld properties. This can best be accomplished by relating a property of each indication to weld properties. This report presents a plan for each of these goals. The objective is to develop the theory of the weld radiograph enigma in special relation to YPPA welded 2219-T87 plate and to establish the effects on mechanical characteristics.

The experimental activity involved examination of indications as they were reported, welding and examining a series of panels prepared, using current welding practice and developing a method to reveal the signature associated with each indication.

## **EXPERIMENTAL PROCEDURES**

### **Materials**

The principal interest is in the 2219-T87 aluminum alloy plate and 2319 filler wire that is normally used in fabricating the space shuttle external tank. These alloys have a nominal composition of 6.3% copper, by weight, as the principal alloying element and a variety of minor elements to achieve specific properties. The compositions are listed in the previous summer research report (1).

### **Welding**

The general conditions for production welding 0.5 inch plate are to clamp the plates in a vertical position with the two plates in contact, held together by manual TIG welded end pieces for starting and runoff. A 5/32 inch tungsten electrode, 5/32 inch orifice, 3° lead angle and 3/16 inch key hole are specified. Specific conditions for the root and cover passes are listed in table 1.

**Table 1. Welding Conditions.**

<b>Control</b>	<b>Root Pass</b>	<b>Cover Pass</b>
current, amps	200	160
voltage	27	22
wire feed, ipm	25	25
P1, CFH	2	2
P2, CFH	5.5	off
welding speed, ipm	7.5	5
shielding gas, CFH	60	60

The panels are mounted, the torch is positioned, adjusted and the system is allowed time to come to steady state. Welding is initiated and completed. The factors that can differ from panel to panel are primarily ambient conditions in the shop which can affect the temperature of the

fixture and the panel. It is also possible that adjustable parameters may be varied, such as the attitude and offset of the torch. These factors will contribute to the thermal distribution. Another factor is the composition of the shield gas. It has been reported (3) that minor impurities, including moisture, affect the surface tension of the liquid metal and in turn affect the direction of motion of the liquid in the weld pool. This has a pronounced effect on the solidification pattern and the resulting reinforcement shape, microstructure and properties. There is general information about the effect of welding variables on weld structure, but there is no specific information about the effect on the structure of YPPA welds on 2219-T87 aluminum.

## Radiography

The procedure of X-ray radiography involves the physical arrangement of the sheet of film in direct or near contact with the welded panel and the X-ray source offset approximately 40 inches from a central point of the weld. The area of the source is controlled to be of the order of 0.2 mm in diameter. Therefore the angle of incidence and the intensity of the radiation vary at each point on the panel. The intensity varies inversely with the square of the distance from the source.

A number of physical processes occur on passage of the radiation through the material. The general interpretation of radiographs is based on shadow contrast, which depends primarily on linear absorption described by Lambert's law,  $I = I_0 e^{-\mu x}$ , where  $I_0$  is the intensity of the incident radiation,  $I$  is the transmitted radiation and  $x$  is the length of the path through the weld. Additionally there is the possibility that certain chemical species will be activated by the energy of the incident beam and, in turn, act as sources of secondary (fluorescent) radiation. A third general process is constructive, or destructive interference of scattered radiation to enhance or further attenuate the transmitted beam. There are also possible refraction and reflection phenomena that might occur. Each of these factors may produce a non-uniformity in the radiation that passes through the panel to darken the emulsion of the film.

Finally, the possible effects of the emulsion characteristics must be considered, along with the development conditions. These factors may enhance or suppress features of the latent image or produce artifacts that have no relation to sample condition.

The term indication will be used to refer to those features that are observed in the radiograph. Most of the indications are related to the shape of the weld and configuration of the plate, some indications may be anomalous or unexplained features origination from some condition in the welded panel or they may be artifacts.

It has been found to be useful and informative to obtain a microdensitometer trace across the weld radiograph (1). The initial application demonstrated the information available in relation to several welds selected for that purpose. See figures 1 and 2. It will be shown that this procedure may be a valuable tool to interpret indications that are not now



clearly understood.

## **Specimen Profile**

A system of computer programs has been written in BASIC to utilize the Macintosh mouse in tracing, digitizing and recording the coordinates of a line around the surface of a test bar. The mouse is the common name of a hand held cursor control for the microcomputer. As it is rolled on a flat surface, signals in two orthogonal components, are transmitted in proportion to its position. These coordinates are available to a BASIC program. By guiding the mouse along the surface the shape of the specimen in the region of interest can be stored and used to compute the intensity of the transmitted radiation through the specimen and the darkening of the film. This, in turn, is used to eliminate the specimen shape effect from the weld radiograph to reveal the signature of the indication.

The mouse orientation is controlled by attachment to a long tube that is pivoted through a TEFLON post. The end of the tube that is attached to the mouse also supports the stylus, which is a small bolt with a conical end. The measurement is made on the specimen that is placed in a standard position, by lightly dragging the mouse with stylus against the surface of the sample while depressing the mouse button. A stop is provided to start the profile from a reproducible, corresponding position on each side of the specimen. The profile is boldly displayed on the screen by circles centered on each measured point. The spacing between data points is regulated by the program. The procedure involves reading points from the front surface, resetting the sample and program then reading points from the back surface.

Equipment is commercially available to perform this function with a greater degree of precision and reliability on welded panels and test bars.

## **RESULTS AND DISCUSSION**

### **General Enigma Theory**

The following is a list of a number of the many indications that include enigmas as well as defects.

- back bead contour, (BBC)
- classic enigma
- straight line indication
- white line
- dark line
- combination
- undercut
- lack-of-fusion
- crack

The method of this investigation is to determine the effect of the indication, regardless of specific type, on the mechanical properties. Two steps must be taken to carry out this work:

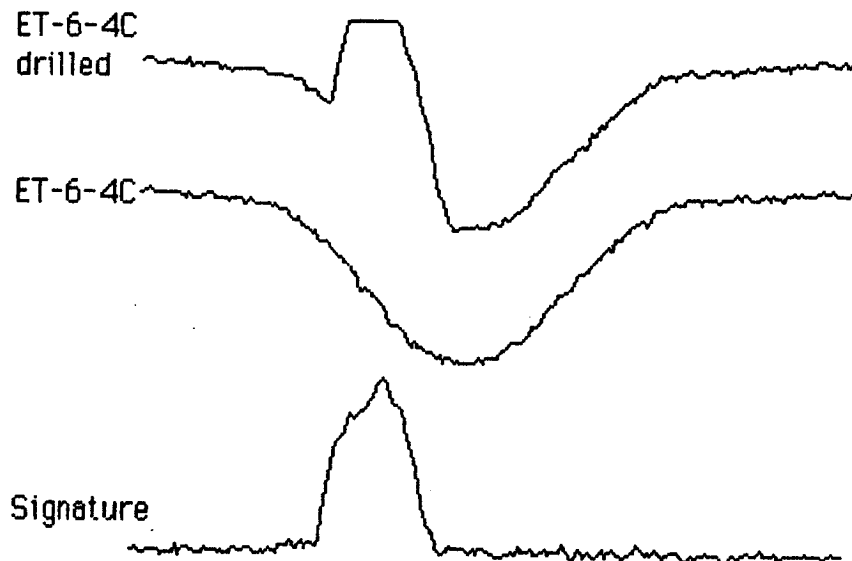
- define a parameter to represent the "intensity" of the indication
- define a procedure to measure this parameter

the indication visual contrast, (IVC), across the weld radiograph is proposed as such a parameter. IVC is the variation of film intensity (darkening) that is above the variation attributable to weld thickness variation. It was introduced in figure 2 as the signature of the indication. These additional factors include:

- any hidden shape, such as internal crack or porosity,
- chemical segregation
- and sample texture.

The experimental procedure to measure the IVC makes use of two finely spaced profiles along the same line. One of these is a microdensitometer trace across the weld radiograph and the other is the thickness trace across the corresponding line of the weld. The X-ray intensity computed on the basis of plate thickness is then subtracted from the measured intensity across the radiograph. The remainder is due to these other factors. Note, that it is possible to substitute a sensitive, direct X-ray detector profile across the panel, along the same line as

the thickness profile. The features of this procedure are illustrated in figure 4.



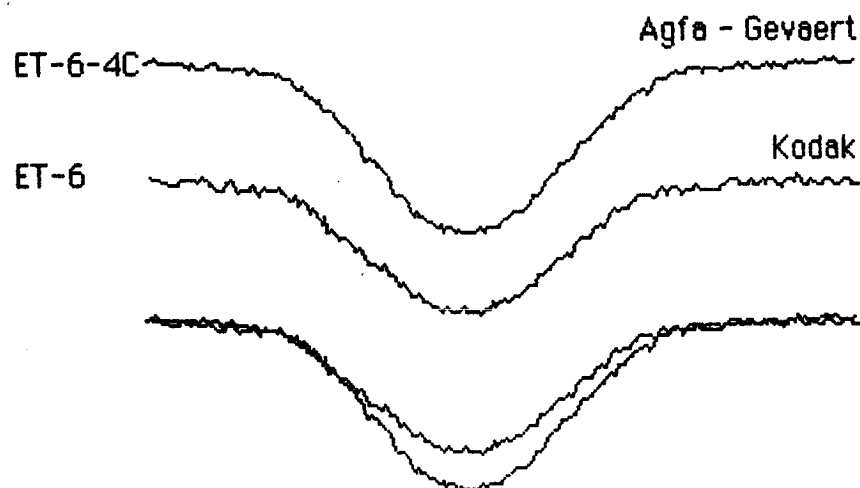
**Figure 4. Derivation of the IVC signature from the weld radiograph microdensitometer trace (top curve) and the intensity profile due to sample shape (represented by the middle curve, which is a microdensitometer trace of the radiograph of the sample before introduction of the defect).**

In this experiment, a number of test bars were cut from panel ET-6. The cut pieces were reassembled and radiographed and the section representing test bar ET-6-4C was profiled across the weld using the microdensitometer. This result is shown as the central trace. After making the radiograph, a hole was drilled through the fusion zone, parallel to the welding direction and the radiograph was repeated. The microdensitometer profile of the corresponding line across the radiograph was also made. This is shown as the top trace above. It is very obvious where the film was darkened due to the reduced specimen thickness. In fact, the resulting intensity of film blackening was too great to be measured by the densitometer.

The third trace shows the point-by-point difference between the two traces. These traces are computer drawn from the microdensitometer data. The features of the third curve are the straight base line along the region where the two radiographs are unaffected by the hole drilled into the specimen for the second determination. This experiment illustrates the

capabilities of the procedure. In the procedure that is recommended and demonstrated in a following section, one trace is to be computed from the thickness trace of the specimen. The difference between the two traces will then truly represent those features in the indication category.

The presentation that follows is subject to overwhelming experimental limitations due to the nature of the equipment that was used. It must be understood that there are many sources of error in procedures involving radiographs. These include conditions of exposure, alignment of the source, positioning of the film and orientation of the specimen. The curves in figure 5 illustrate the effect of using X-ray film from different manufacturers (there is no intention to indicate preference). The curves are shown separately and close together. The original film was manufactured by the Kodak company and the exposure was made in May. The more recent radiograph, made in August, after the test bars were cut, utilized Agfa-Gevaert film. The two traces are along corresponding lines. The choice of film is made on the basis of cost.



**Figure 5. The effect of film characteristics on the microdensitometer trace across panel ET-6.**

Classical, straight line, dark line and white line indications have been identified in relation to radiographs of welded 2219-T87 aluminum alloy. Mattheessen (4) described these as two types. The classic enigma always appears at a small angle to the weld center-line, is always slightly curved, always shows as an indistinct dark shadow with accompanying light halo, usually disappears when the radiation angle is varied  $\pm 15^\circ$ , and may vary in intensity. The Straight Line always appears on, or parallel to, the weld centerline, is always straight, generally distinct, may be dark only, light only, or combined, light indications and dark/light

combinations always appear to one side of the weld centerline, dark indications may appear on weld centerline or to one side. The indication changes shape when the radiation angle is varied, it usually does not disappear, and may vary in intensity.

## Multiple Diffraction

The problem is to determine the nature of the pattern that is produced on a radiographic film due to the interaction of the broad, incident polychromatic X-ray beam with the thick, polycrystalline, textured sample. The fine structure in the image is due to real features of structure in the specimen. There is continuing evidence to support the observation that both dark, light and combination features are present in weld radiographs and that these features are not clearly attributable to absorption (Lambert's law) and shadow formation alone. The physical mechanism involved in the production of the indication on the film may be due to a variety of factors as described in the previous report. However, it is believed that special attention should be given to multiple diffraction.

There exists a spectrum of severity with the least pronounced features related to conditions in the specimen that do not affect engineering properties and with real defects at the other extreme. A principal goal in this research is to adequately describe possible features in relation to this scale. The effects on mechanical behavior will be left for separate study.

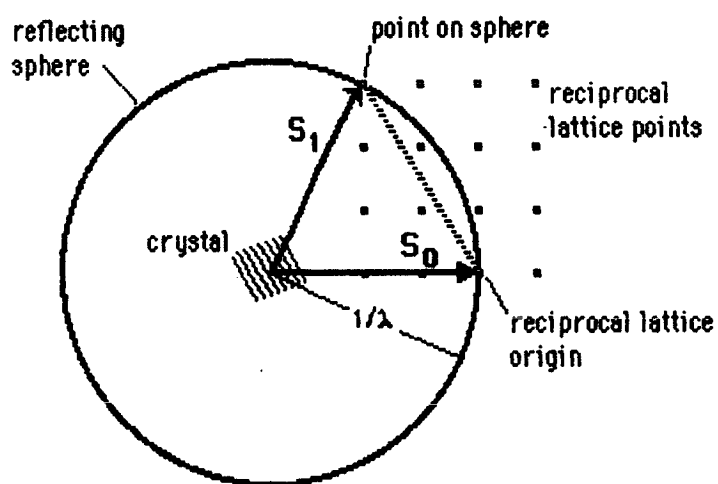
The composition, microstructure and texture of the sample play a major role in image formation. Most experimental work, in relation to physical theory, has been performed on ideal single crystals with small dimensions. Chang (5) reviews multiple diffraction in relation to a number of parameters that are of interest in the radiography of thick samples. He also indicates that research has been performed with compositional variations and on polycrystals.

Recent work by Ding (6) shows that only small changes in welding conditions result in the formation of large, dendritic grains in the fusion zone. Ding developed exaggerated grain sizes in the root pass by cooling the panel with a stream of cold argon gas immediately behind the plasma jet at the back of the weld. Rummell found that large, oriented grains favored enigma formation (7). He related the diffraction effect to the formation of a dark line, probably towards the side of the fusion zone. However, the theory of multiple diffraction provides an explanation for centerline intensification.

The most convenient method to represent simple and multiple diffraction is through the use of the Ewald construction. In this method, the incident radiation is represented by a vector,  $S_0$ , of length  $1/\lambda$ , where  $\lambda$  is the wave length of the radiation. The vector points in the direction of propagation. The vector also is the radius of a sphere, which is represented by a circular trace on the drawing. This is called the reflecting, or Ewald sphere. The point where  $S_0$  contacts the sphere is also taken to be the location of the center of the reciprocal lattice of the sample. The reciprocal lattice is strictly a conceptual device. Every real crystal has an associated reciprocal lattice. Each lattice point, of which there are an unlimited number,

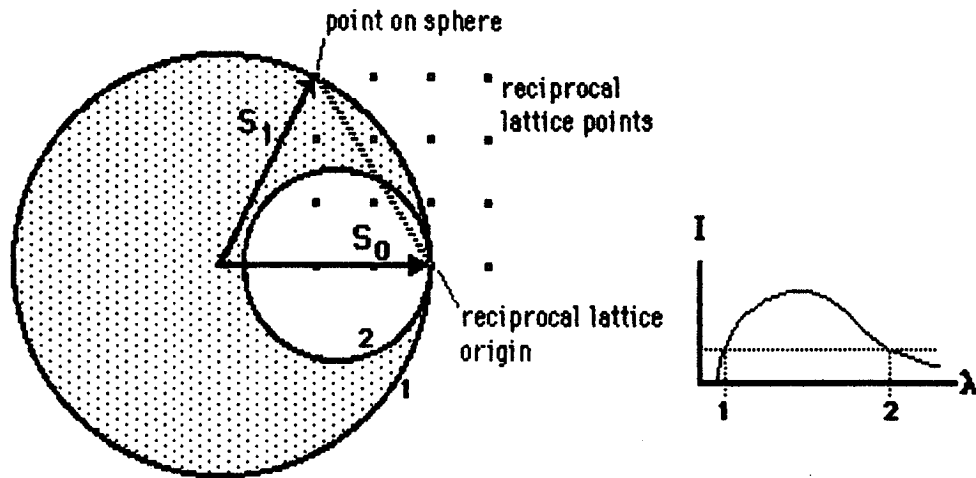
represents a set of crystallographic planes in the real crystal. The radius vector, from the origin of the reciprocal lattice to a given point, is perpendicular to the planes of that set and has a length that is the reciprocal of the interplanar spacing.

The Ewald construction is illustrated in Figure 6 for the simple diffraction condition of a crystal aligned for diffraction in the direction of the  $S_1$  vector. The diffracted beam actually comes from the sample, which is generally represented at the center of the reflecting sphere. The reciprocal lattice is always oriented in alignment with the orientation of the real crystal. The principal relation of the Ewald construction is that the diffraction conditions are satisfied, and a diffracted beam is produced, for each point of contact between a reciprocal lattice point and the reflecting sphere. This construction supports simple visualization of the conditions for diffraction.



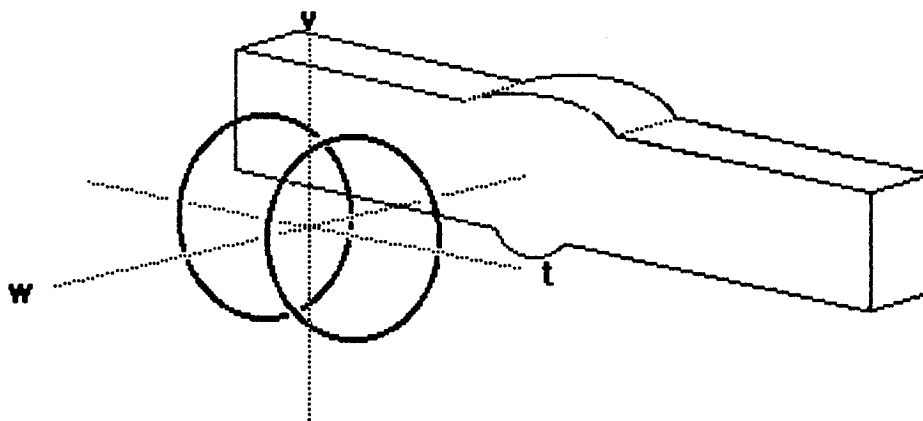
**Figure 6. Ewald construction for simple diffraction.**

The next figure shows the Ewald construction for a polychromatic X-ray beam. The spectrum of the radiation, which is typical of that used for radiography, is shown at the right. A dotted line is drawn across the spectrum to mark the level of discrimination and the two extremes are marked as 1 and 2. This same notation is used to indicate the Ewald sphere that is related to each. Since the radiation is continuous between these two limits, the Ewald diffraction region on the diagram lies between the two corresponding circles, and is filled with dots. A large number of reciprocal lattice points will now satisfy diffraction. Only two of the additional points are shown, but the pattern can be extended to cover the total Ewald figure. Each point falling within the dotted region will account for a diffracted beam from the sample.



**Figure 7. Ewald construction for diffraction using polychromatic radiation as represented in the figure at the right.**

A polycrystalline sample is represented by an appropriate enhancement of the reciprocal lattice. The reciprocal lattice of a typical dendritic weld fusion zone is illustrated in the following figure. This is a rather ideal structure in which the dendrites are all aligned with their axes (the easy growth direction) parallel to the transverse axis, marked  $t$ , but with no restriction on orientation about this axis. This is a "fiber texture" aligned on  $t$ . The reciprocal lattice points for a large group of dendrites with this texture are arranged, symmetrically in circular arcs. Only two are shown. There will be others in the  $w$ - $v$  plane as well as those in general locations.

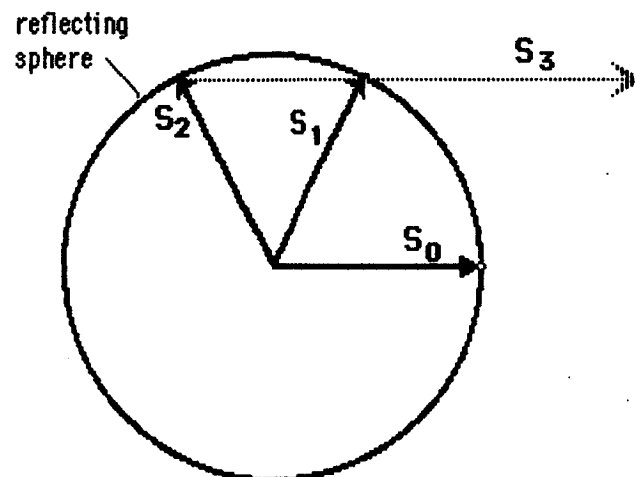


**Figure 8. A portion of the reciprocal lattice of the dendritic structure of the weld fusion zone.**

The coordinate axes are labeled  $w$ ,  $v$ ,  $t$  to represent the welding, transverse and vertical directions, respectively. A sketch of a typical test bar is shown in the background. The orientation of the reciprocal lattice circles is representative of the typical dendrites that point into the weld center from the HAZ. If the dendrites grow from the base, the axes should be interchanged so that the circles are oriented with the axis upward. The circles are generated by rotating the reciprocal lattice for a single crystal about the appropriate axis, which is the axis of orientation freedom for the structure.

Weld radiograph enigma (WRE) features are narrow and elongated in the welding direction. Any theory of WRE formation must provide for this geometry. Therefore, broad angle scattering must not overlap to obscure the linear features. The WRE must either be due to a linear feature in the weld or to X-ray scattering that produces linear features. In the case of the structure of figure 8, referring to the Ewald construction, it can be seen that the X-rays, normally directed along  $v$  in the negative sense, intersect the reflecting region between the limiting spheres along arcs. This accounts for lines of diffracted radiation generally aligned in the welding direction. These, however, are directed away from the direction of propagation and contribute, primarily to the background of the radiographic film.

In a sufficiently thick sample, the diffracted rays can themselves serve as incident beams for subsequent, secondary diffraction. This is depicted in the figure 9 which shows the situation in which two reciprocal lattice points fall simultaneously on the reflecting sphere. In high symmetry crystals, such as FCC aluminum, such symmetric relationships are common. In this case, the two diffracted beams,  $S_1$  and  $S_2$  satisfy diffraction conditions between them for either to act as the initial beam and the other as the diffracted beam. The secondary diffraction,  $S_3$ , is parallel to the incident beam,  $S_0$ .



**Figure 9. The general condition for multiple diffraction.**



Fricke & Gerold (8) and Thomas & Franks (9) give examples where a small misorientation of the dendrites from the ideal  $\langle 100 \rangle$  produces broadening of the central beam. This effect can contribute to the classic enigma, for example.

The structural condition of the sample is still of primary concern. These diffraction effects depend on special sample conditions. First, the sample must contain large grains or clusters of closely oriented regions, such as the dendrites that are just slightly misaligned. The misalignment can also be provided by a variation in alloy content. This has the effect of altering the diffraction angle (it varies the spacing of the reciprocal lattice points, thus requiring a small reorientation to keep diffracting points on the reflection sphere). The misorientation between dendrites in the fusion zone can arise during solidification due to small compositional and thermal variations. A more likely cause is plastic deformation occurring during cooling of the newly solidified alloy. This distortion will have a direct effect on the orientation in the deformed region and will also affect the orientation of the continuing dendritic growth. These effects may be cumulative. Any enigma associated with such structural features will have an associated alteration in mechanical properties. The hardness of the fusion zone is known to be lower than that of the parent metal or HAZ. The controlling parameter is recognized to be the secondary dendrite branch spacing.

The pronounced emphasis that is placed on the microstructural condition of the specimen by most investigators indicates that more information is needed about the effect of welding parameters on microstructure in TIG and YPPA welded 2219-T87. A parametric study, dedicated to this objective will provide useful and necessary information.

## **Enigma Production**

Table 2 is a list of indications, and their occurrences out of 1259.5 inches total weld length of the ET series panels. These panels were welded on three fixtures under the conditions described above and subjected to X-ray radiographic inspection only. A number of indications were marked on the film. These were examined, measured and found to have the following occurrences. It was found that all linear indications, excepting the classic enigma, were due to back bead contrast.

## **Weld Radiograph Screening Procedure**

The procedure for determining the signature and magnitude of the indication requires two profiles. The specimen thickness profile has been briefly described and the microdensitometer profile of the weld radiograph is made using commercial equipment. A search was made of available profiling facilities at this location, but none was found that could generate and store coordinates automatically. A number of profilers produce digital indications of the position of machine tool components, but are not designed to follow or trace a contour, and the coordinates must be manually copied from the display. Therefore the

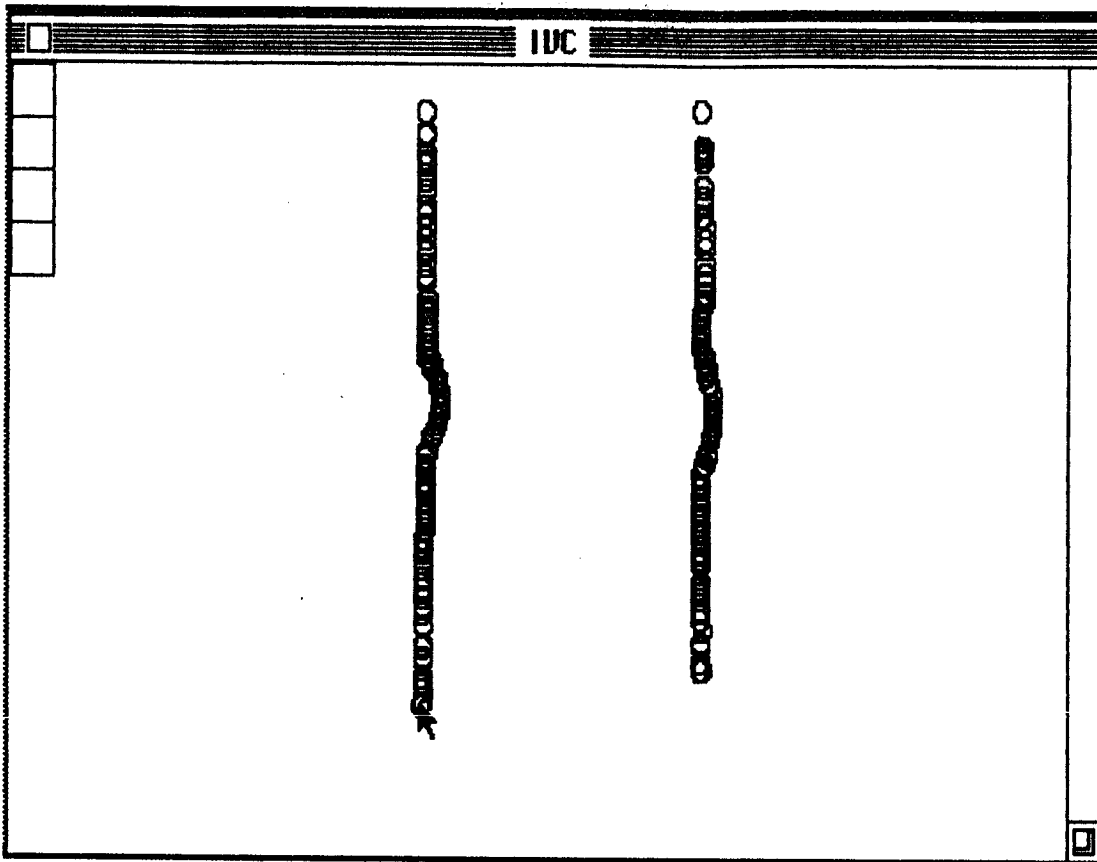
Macintosh computer was adopted for a preliminary demonstration. However, equipment is commercially available for this purpose. The procedure used on the Macintosh is described along with some of the preliminary results. Three computer programs were written in BASIC to implement the operations.

**Table 2. Summary of Indications in ET Panels.**

INDICATION	DIMENSION	TOTAL	PERCENT
Undesignated	inches	172.4	13.7
white line	"	225.0	17.9
classic enigma	"	21.3	1.7
undercut	"	59.2	4.7
lack-of-fusion	"	30.3	2.4
pinholes	count	17	DNA
misaligned	"	2	"
tungsten inclusion	"	1	"

In the first step, the front and back surfaces of a test bar are traced along coordinated lines. They are on opposite surfaces of the test bar and started from opposing points. The end of each trace is independent of the other. Figure 10 is a copy of the image on the screen after the two traces have been made.

In this illustration, the right hand trace was made first along the front surface of the test bar. The circles are each centered on the point representing the position of the mouse. They are used simply as an easy to observe feature to facilitate the mouse control. If the circles are not evenly spaced, or close enough, the run is terminated and repeated. The trace of the back side is displayed to the left. The last point is under the cursor image (arrow). The other features are for program control. The next step in data processing is the inversion of the back trace and translation into the proper position in relation to the front trace at the correct spacing. The result of these operations is shown in figure 11.

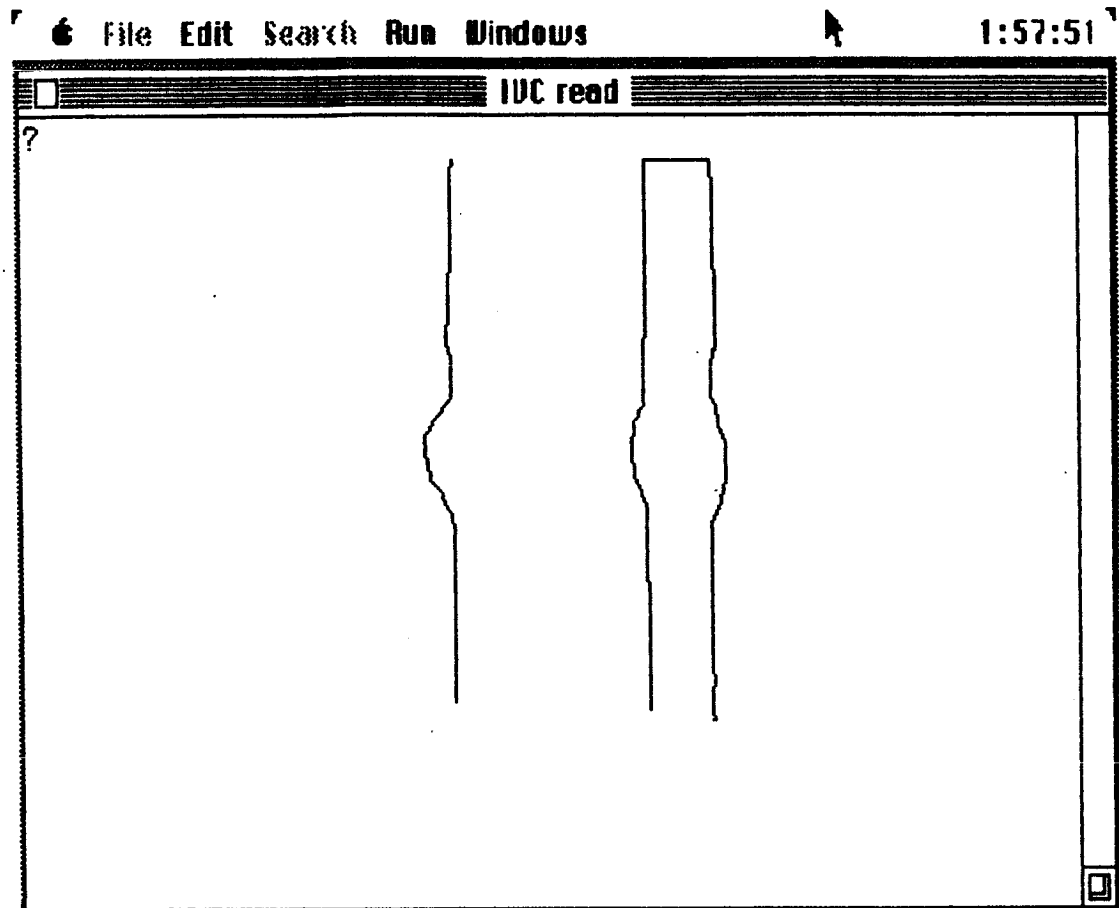


**Figure 11. Macintosh screen with data input display.**

In this view, the two traces have been reassembled. The third trace is the thickness profile computed from the shape. The mouse directional guidance system is necessary to keep parallel traces parallel. In the system used, the mouse is constrained to a direction radiating from a fixed point. As long as the surfaces being traced are aligned along radial directions, there is no error in alignment of the traces. The final step of combining the above trace with the microdensitometer trace is illustrated below.

Microdensitometer traces were made on corresponding regions of radiographs of panel ET-1, where classical enigma features were indicated. These radiographs were of the Kodak and Gevaert types. The thickness profiles were made on the cut pieces from these two regions. The test bar numbers are ET-1-1E and ET-1-2E. The codes and their descriptions, associated with these specimens, are described in the table 3.

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**Figure 12. MacIntosh screen showing weld bar shape (right) and thickness profile (left).**

A step wedge, made of the same aluminum alloy (2219) was used to calibrate both the microdensitometer measurements and the horizontal and vertical scale factors of the thickness profiling system. Since it was observed that the film intensity varies markedly with manufacturer, exposure and processing conditions as well as the condition of the sample, a sample exposure with the step wedge was made. The curve in figure 12 shows the variation of film density as a function of thickness.

**Table 3. Data Codes and Their Descriptions.**

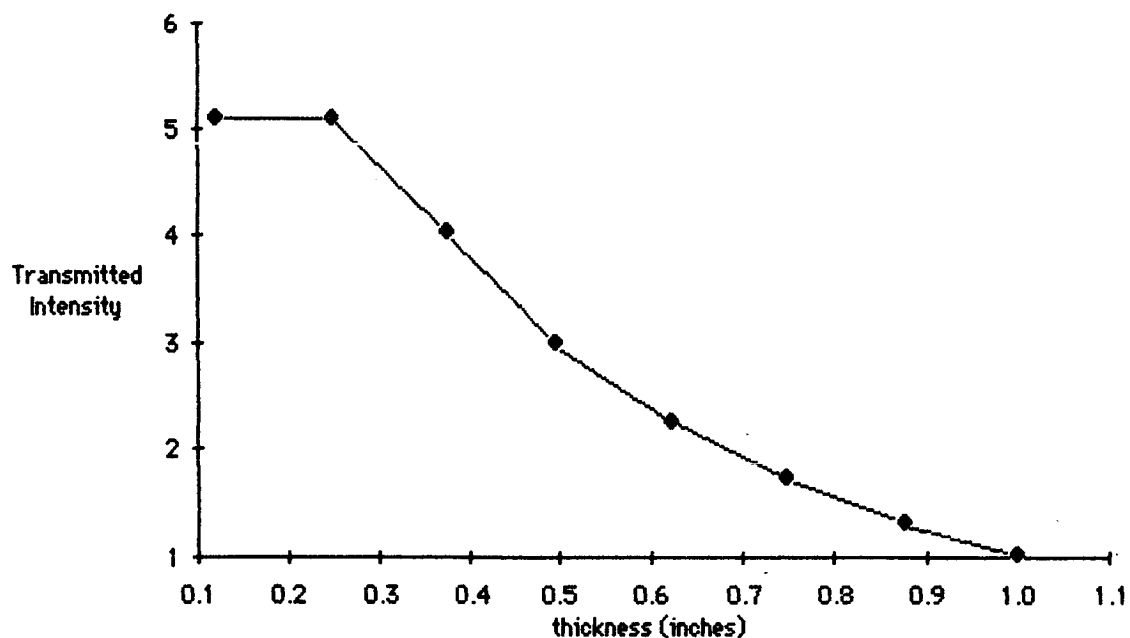
<b>CODE</b>	<b>DESCRIPTION</b>
ET-1	welded panel
ET-1-1E	File containing thickness trace from test bar ET-1-1E
ET-1-2E	File containing thickness trace from test bar ET-1-2E
et11e	File containing thickness trace of ET-1-1E
et12e	File containing thickness trace of ET-1-2E
tr4	Program with microdensitometer data of ET-1-1E (K)
tr5	Program with microdensitometer data of ET-1-1E (G)
tr6	Program with microdensitometer data of ET-1-1E (K)
tr7	Program with microdensitometer data of ET-1-1E (G)
tr4s	File with microdensitometer data of ET-1-1E
tr5s	File with microdensitometer data of ET-1-1E
tr6s	File with microdensitometer data of ET-1-1E
tr7s	File with microdensitometer data of ET-1-1E

(G) radiograph made with Gevaert film

(K) radiograph made with Kodak film

A microdensitometer profile was made along this radiograph under the same conditions used for the weld specimens. Gevaert film was used. A surface profile was also made of this step wedge, from which the scale factors were determined. These calibration factors were then entered into the appropriate computer programs for scaling.

The third BASIC program reads thickness profile and microdensitometer data, displays the traces simultaneously, to the same scale, on the screen, provides a mechanism for manual alignment and finally performs the computation for the signature. Since the precision of the two profiling systems are so different, the result is not as satisfying, nor meaningful as the comparisons made between radiographic traces. However, certain features of the method are illustrated.



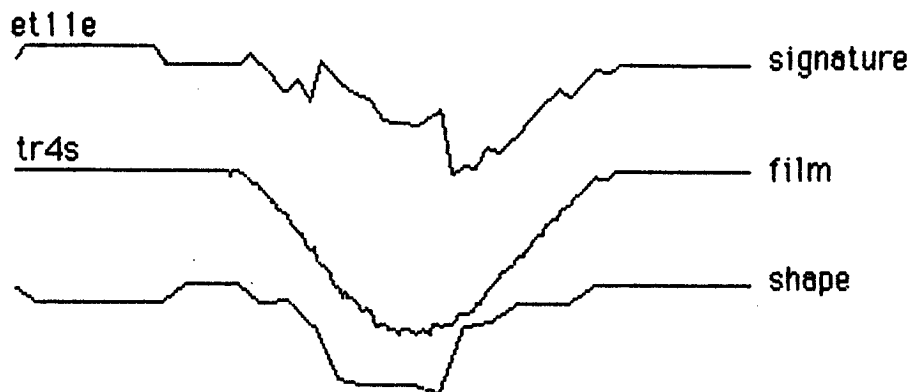
**Figure 13. Film darkening as a function of specimen thickness.**

In the first example (figure 13) the microdensitometer trace included a film marking made by the radiographer. The thickness profile does not match the dimensions of the other profile, principally due to the large size ( $\approx 0.005$  inches radius) of the tip of the stylus, for which no correction was made. Another source of error in the thickness trace is in connection with the simplified data processing procedure that was used to coordinate intensity values at points that did not exactly correspond to those points along the traces of the two sides.



**Figure 13. Signature generation.**

A similar error was introduced in converting the thickness profile to X-ray intensity, using the intensity values from the step wedge. The curves of figure 13 show that the features of the signature are related to the features of the two profiles. The example shown in figure 14 matches the same thickness profile with the features of the radiograph made with Kodak film.



**Figure 14. Signature generation.**

The background exposure saturated the film, with respect to the densitometer. The details in the weld, however, are clearly displayed. The resulting signature is much more regular. The quality and significance of the signature is dependent, of course, on the alignment between the two profiles. This alignment includes both ends of the pair of traces. The next two sets of traces relate to the second enigma containing test bar from panel ET-1.



**Figure 15. Signature generation.**

In figure 15, the details of the HAZ and base metal are included in the signature in reference to the saturated regions of the original radiograph. The signature across the region of the center of the weld shows that the accumulated errors obscure any meaningful interpretation with respect to radiographic indications.



**Figure 16. Signature generation.**

The last set of the four, referring to the older film with saturated base metal regions, appears to be the least obscured by problems associated with markings on the film, alignment of the traces, etc. It confirms the accumulated errors but indicates the possibilities in the method. The region across the center of the weld indicates a type of match between the two profiles.



## **CONCLUSIONS AND RECOMMENDATIONS**

The weld radiograph enigma must be treated as a part of the spectrum of indications that can be observed. There are numerous reports of a number of these indications, with as many interpretations. The most significant and immediate need is for a method to reliably interpret the possible effect on mechanical properties. In this report, a method is explained that provides a means to represent all weld radiograph indications on a common scale that can be used to interpret production data. This system can also be used in a program to quantify the relation of the indication to weld mechanical properties. The method involves the determination of the signature of the indication and its magnitude. The signature is graphical display of the difference between the microdensitometer trace of the weld radiograph and the trace computed from the thickness profile across the same region. This net trace represents all features excepting the thickness variation, which is directly apparent. Each type of indication will have a characteristic appearance above the base line that is expected for a weld of uniform structure. The maximum magnitude of the deviation from the base line is the numerical parameter that is characteristic of the indication. Preliminary measurements indicate that defects have a magnitude that are more than 5 times that of typical enigma features. Since this is a report of a survey, it is strongly recommended that the following activities be pursued in relation to TIG and YPPA welded 2219-T87 alloy.

- Evaluate the effect of welding conditions on weld microstructure.
- Develop methods to produce each enigma type.
- Evaluate the effect of each on mechanical characteristics.
- Develop the theory of each feature.

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